Article

Survival, Development, and Fecundity of *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on Various Host Plant Species and Their Implication for the Pest Management

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Simple Summary: *Spodoptera frugiperda* is an invasive pest of corn in several countries including Indonesia. The pest is a highly polyphagous with a limited information on its biological parameters. This information about its biological parameters such as survival, life cycle, and fecundity using different host plant could be critical to develop effective pest management strategies in Indonesia. After testing 14 different host plants we found that even though *S. frugiperda* preferred corn as the main host, several host plant i.e., papaya, water spinach, banana, spinach, cucumber, and a weed (coco grass) can act as alternate host for *S. frugiperda*, implying the use of these plants as hedge or trap plant in management of this pest using cultural technique manipulation. However, other control methods need to be considered for further research to develop sustainable solutions for its management.

Abstract: *Spodoptera frugiperda* is a relatively new invasive polyphagous insect pest in Indonesia. So far, *S. frugiperda* infestation has only been reported in corn, however in other countries *S. frugiperda* has been known to attack many commercial crops. To date, information on biological parameters of *S. frugiperda* is limited in Indonesian ecologies. Since host plants are a critical factor for insect life-history and has the potential to be used for pest control strategies, it is important to study the biology and survival of *S. frugiperda* on different host plants. This research was aimed to study the survival, life cycle, and fecundity of *S. frugiperda* on different host plants and how it affects pest management. The study was conducted by rearing *S. frugiperda* on 14 common cultivated host plant species in Indonesia. Survival rate, development time, fecundity, and potential attack rate of *S. frugiperda* on various tested host plants were analyzed in this study. The findings revealed that corn was the main host for *S. frugiperda*. The ability of *S. frugiperda* to survive on papaya, water spinach, banana, spinach, cucumber, and coco grass indicates that these plants are potential alternate host for *S. frugiperda*. Long beans, bok choy, choy sum, and beans might be indicated as a shelter for *S. frugiperda*. Meanwhile, inappropriate hosts for *S. frugiperda* include cabbage, broccoli, and cauliflower due to their low survival rate on these plants. This research implies that these plants have the potential to be used as a hedge, trap, or bunker plant in *S. frugiperda* management strategies. However, to prevent a detrimental damage, control methods are needed in integrated manner, including monitoring pest populations, environmental engineering, and conservation of natural enemies.

Keywords: fall armyworm; integrated pest management; invasive pest; *Spodoptera frugiperda*

1. Introduction

America is where the fall armyworm (*Spodoptera frugiperda*) first appeared [1]. *Spodop*

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tera frugiperda aggressively spread to the African Continent in 2016 [2] and Asian Continent in 2018 [3]. *Spodoptera frugiperda* was first discovered in the Asian Continent in India, and spread to others Asian countries including China, Taiwan, Japan, Cambodia, Malaysia, and the Philippines [2,4,5,6]. In Indonesia, *S. frugiperda* firstly reported to be found in West Pasaman, Lampung, and West Sumatra [3]. *Spodoptera frugiperda* has currently expanded across the entire islands of Indonesia [7].

Spodoptera frugiperda attacks corn as its main host and could harm corn plants at any stage, including both the vegetative and generative stages [8], while the most severe damage occurred in the vegetative phase [9]. *Spodoptera frugiperda* can attack the growing points of corn plants, causing the failure of the formation of young leaves or shoots. Larvae that damage cobs can cause losses, thereby reducing crop yields [10]. Despite having corn as its main host plant, *S. frugiperda* has been reported to have a wide range of host plants, including 353 host plants from 76 plant families, such as Poaceae, Fabaceae, Solanaceae, Amaranthaceae, Brassicaceae, Caricaceae, Cyperaceae, Euphorbiaceae, and Cucurbitaceae [11].

Indonesia is an agricultural country with a vary landscape structure. Even though most paddy fields are used for growing rice [12], some farmers typically cultivate other crops such as corn, chilies, onions, beans, and green vegetables, in which the fields are surrounded with coconut, mango, cassava, bananas, papaya, or shrubs [13]. *Spodoptera frugiperda* has a wide variety of hosts, giving it the opportunity to attack various plants. Additionally, the adults of *S. frugiperda* can migrate from one location to another due of its excellent flying ability [14]. However, it hasn't been known whether all these host plants can support the development of *S. frugiperda*. Research on the life cycle of *S. frugiperda* in several host plants has been carried out either in Indonesia [15, 16, 17, 18, 19] or other countries [20, 21, 22, 23]. Research on life cycle is critical because, in addition to the impact of plant species [20, 24], geographic location can also affect insect bioecology differently due to varying climatic conditions [25, 26]. Moreover, those studies discussed the effect of diet (host plant) on the survival and or development of *S. frugiperda*. However, the implications of the research results for the potential of *S. frugiperda* attack on other plants and the control measures that can be taken have not been much either analyzed or discussed yet. Therefore, this research was conducted to study the biological parameters of *S. frugiperda* in various host plant species and its implications for pest management.

2. Materials and Methods

2.1. Spodoptera frugiperda

Spodoptera frugiperda used in this study were collected from corn fields around Kasihan, Bantul, Special Region of Yogyakarta, Indonesia. *Spodoptera frugiperda* then reared in the laboratory insect rearing room (25±1^{0}C, 80±10% rh, 16L:8D) of the Department of Agrotechnology, Faculty of Agriculture, Universitas Muhammadiyah Yogyakarta. Larvae were kept solitary using a cup (6.4 in height x 3.8 cm in diameter) to avoid cannibalism. Larvae were fed with baby corn purchased at the market and cleaned before being given using tap water. After the larvae transformed into a pupa, they were then transfer into a cylindrical adult cage (30 in height x 10 cm in diameter) covered with paper as an oviposition medium. Adult reared until laying eggs and given a 20% honey solution moistened on cotton as a diet source. The eggs obtained were used for research purposes.

2.2. Diet Source

Fourteen plants were purposively selected to be tested as a diet source for *S. frugiperda* (Table 1). These plants were selected based on the *S. frugiperda* host range database [14] and the variety of vegetable cultivated in Indonesia. Corn was used as a comparative host (control). Meanwhile, coco grass is also used as a diet source based on preliminary observations of *S. frugiperda* on this plant during field observations. Plants used were obtained either from the field and market. Plants were prepared as above before it feed to *S.*

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frugiperda.

2.3. Effect of different diet on the survival, development, and fecundity of S. frugiperda

The selected host plants (diet) were applied as treatments. Each treatment was replicated four times using 20 larvae in each replication. In total, there were 56 experimental units and 1120 larvae used during this research.

Spodoptera frugiperda eggs that had just hatched into first instar larvae were transferred into a cup (6.4 in height x 3.8 cm in diameter) using a brush carefully. Each replication (20 cups) was separated using a plastic tray. The prepared diet was given daily until the larvae reached the sixth instar. After pupation, the pupae were transferred to an adult cage covered with paper as an oviposition medium. Adult were reared until they laid eggs and were given a 20% honey solution moistened on cotton as a diet source. The development of *S. frugiperda* was observed and recorded daily to determine the survival rate, development time of each stage including eggs, larvae, pupae, and adults. When the insects became adults, the number of eggs laid was counted daily until they died to measure fecundity.

Table 1. Host plants used during the experiment.

Host Plant	Family	Common Name	Diet form
Zea mays	Poaceae	Corn	Baby corn
Cucumis sativus	Cucurbitaceae	Cucumber	Leaf
Brassica oleracea var. *italica*	Brassicaceae	Broccoli	Bud
Brassica oleracea var. *botrytis*	Brassicaceae	Cauli flower	Bud
Brassica oleracea var. *capitata*	Brassicaceae	Cabbage	Bud
Brassica rapa subsp. *chinensis* var. *parachinensis*	Brassicaceae	Choy sum	Leaf
Brassica rapa subsp. *chinensis*	Brassicaceae	Bok choy	Leaf
Phaseolus vulgaris	Fabaceae	Bean	Pod
Vigna unguiculata ssp. *sesquipedalis*	Fabaceae	Long bean	Pod
Amaranthus viridis	Amaranthaceae	Spinach/ green amaranth	Leaf
Ipomoea aquatica	Convolvulaceae	Water spinach	Leaf
Musa sp.	Musaceae	Banana	Leaf
Carica papaya	Caricaeae	Papaya	Leaf
Cyperus rotundus	Cyperaceae	Coco grass	Leaf

2.4. Data Analysis

Kaplan Meier's Survival Analysis was used to assess the survival data [27]. Meanwhile, development time and fecundity data were subjected to stepwise simplification to determine the appropriate model based on the AIC value. The final model was analyzed using a general linear model (GLM) with gaussian family and log link function except for pupal development time which was analyzed with gamma family and identity function. Tukey's HSD multiple comparisons with Holm's adjustment was used to further assess the mean difference between treatments [28]. Finally, the survival data of *S. frugiperda* on each plant was also subjected to multiple regression analysis to assess the likelihood of attack rate if the host plants tested are intercropped. R Statistics v 4.2.1 [29] was used for the statistical analysis, and the ggplot2 package was used to display the graph [30].

3. Results

The results showed that host plant significantly affected the survival rate of *S. frugiperda* ($P < 0.0001$) (Figure 1). The highest survival rate (> 85%) occurred when *S. frugiperda*

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fed on corn, papaya, and water spinach. In general, the survival rate began to decrease at the 2nd and 3rd instar larvae and continued to decrease until adult stage, with 88.75% final survival rate for *S. frugiperda* fed on corn and papaya and 86.25% for those on water spinach. The survival rate of *S. frugiperda* was also quite high (80-85%) when they fed on banana (82.5%), spinach (81.25%), cucumber (80%), and coco grass (80%). *Spodoptera frugiperda* had a 71% survival rate when fed on bok choy, and 77.5% when fed on long beans. Conversely, the survival rate of *S. frugiperda* was only 47.5% and 51%, respectively, when fed on beans and choy sum. No *S. frugiperda* survived (0% survival rate) when fed on broccoli, cabbage, and cauliflower. Mortality began to occur when *S. frugiperda* at the 4th or 5th instar larvae when reared with cabbage and broccoli and at the pupal stage when fed on cauliflower.

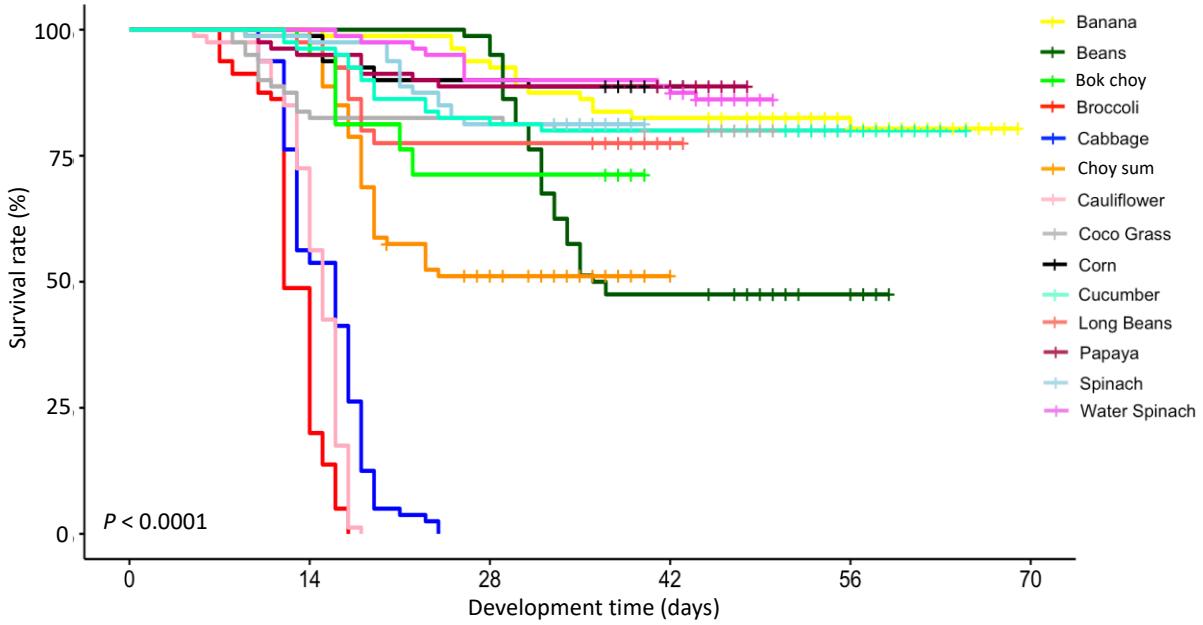

Figure 1. The survival rate of *Spodoptera frugiperda* feed on various host plant species

The development time of *S. frugiperda* was also strongly influenced by host plant (Figure 2). The development time of *S. frugiperda* from egg (GLM: $F_{10.33} = 54.926$, $P < 0.001$), larva (GLM: $F_{10.33} = 46.837$, $P < 0.001$), pupa (GLM: $F_{10.33} = 23.741$, $P < 0.001$), and adult (GLM: $F_{10.33} = 102.05$, $P < 0.001$) varied significantly when they fed on different diet. The development time was either longer or slower compared to the development time in its main host (corn). The eggs produced by adult, whose larvae fed on beans, coco grass, banana, spinach, bok choy, and choy sum, developed within two days, the same as those on the main host (corn). Meanwhile, the eggs produced by adult, whose larvae fed on cucumber, water spinach, papaya, and long beans, developed a day slower (three days). Development time of larval stage showed interesting results. When the larvae were fed on corn, the larvae developed for 18 days, like those fed on bok choy and papaya. The larvae developed two days faster when reared with choy sum and long beans. Meanwhile, the larvae developed a day slower when fed on spinach, three days on water spinach and banana, nine days on cucumber, and 13 days on beans. Pupae developed within nine days when the larvae fed on corn. The same results were observed when they were fed on beans, coco grass, long beans, bok choy, papaya, and spinach. Pupae developed 4-7 days longer when the larvae fed on banana and water spinach. Adults also lived for nine days when their larvae were fed on corn. Adults lived shorter by one day when the larvae fed on bok choy, two days on choy sum, and three days on banana, beans, spinach, and water spinach. However,

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adults raise from the larvae fed on long beans could survive one day longer, two days longer with cucumber, and up to five days longer with papaya and coco grass. The total development time of *S. frugiperda* was longer when the larvae fed on water spinach, papaya, beans, banana, coco grass, and the longest when they fed on cucumber.

There was also significant effect of the host plant on the fecundity of adult females (GLM: $F_{10.33} = 50.884$, $P < 0.001$) (Figure 3). One adult female raises from the larvae fed on corn could produce 228 eggs during her lifetime. This number is not significantly different from those treated with spinach and bok choy. Adult females whose larvae were fed on papaya produced 65% more eggs than adults whose larvae were fed on corn. Females from the choy sum treatment also produced 55% more eggs. Despite the longer adult life span of *S. frugiperda* in the cucumber and coco grass treatments, the fecundity in the two treatments surprisingly showed opposite results. Adult females, which during their larval stages were fed on cucumber, could only produce 18 eggs. Meanwhile, adult female raises from the larvae fed on coco grass could produce up to 600 eggs.

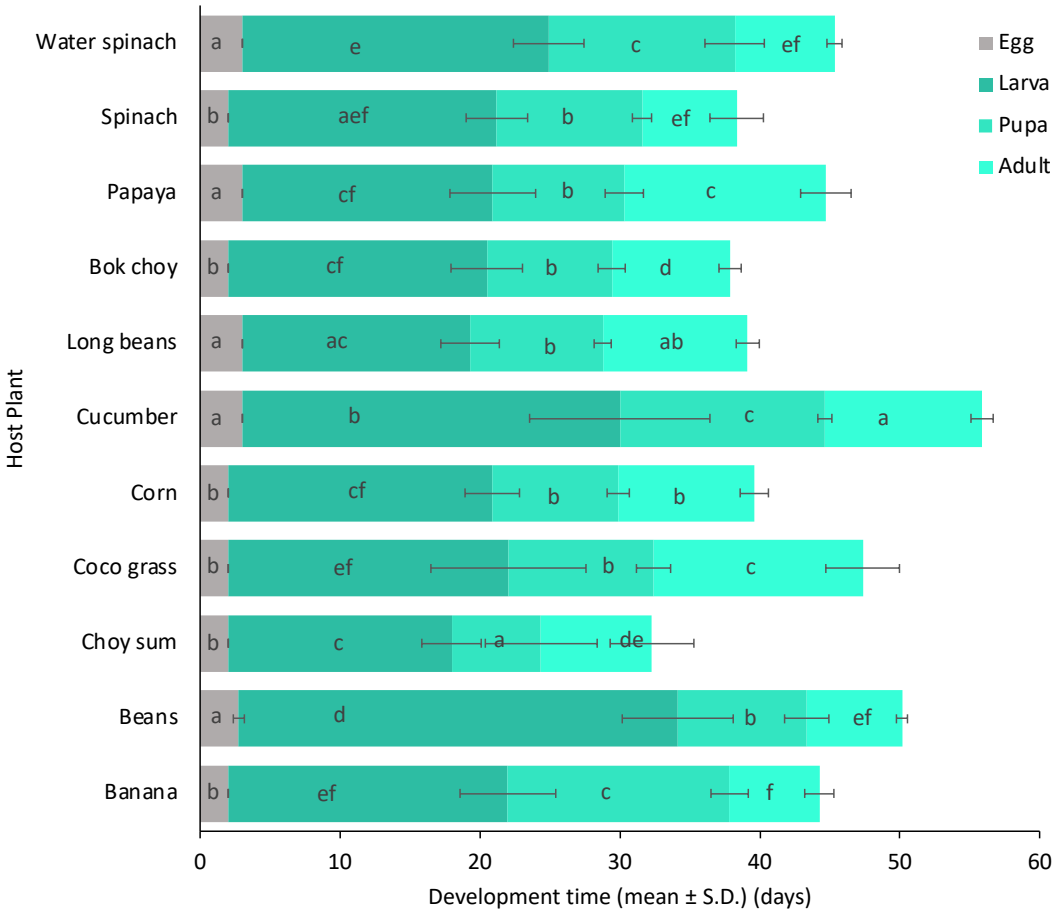

Figure 2. Development time of *Spodoptera frugiperda* on various host plant species. SD, standard deviation. Means with different letter are significantly different by Tukey HSD Test ($\alpha = 0.05$).

Multiple regression analysis revealed that nearly all the host plants employed in this study might result in a high attack rate of *S. frugiperda* when the host plants intercropped with one another. Even broccoli, cabbage, and cauliflower as the least suitable hosts for *S. frugiperda* may cause at least 50% damage when they planted with other crops.

4. Discussion

Spodoptera frugiperda is a polyphagous insect with 353 host plants species [11]. However, facts in the field report that *S. frugiperda* more often feeds corn plants with different

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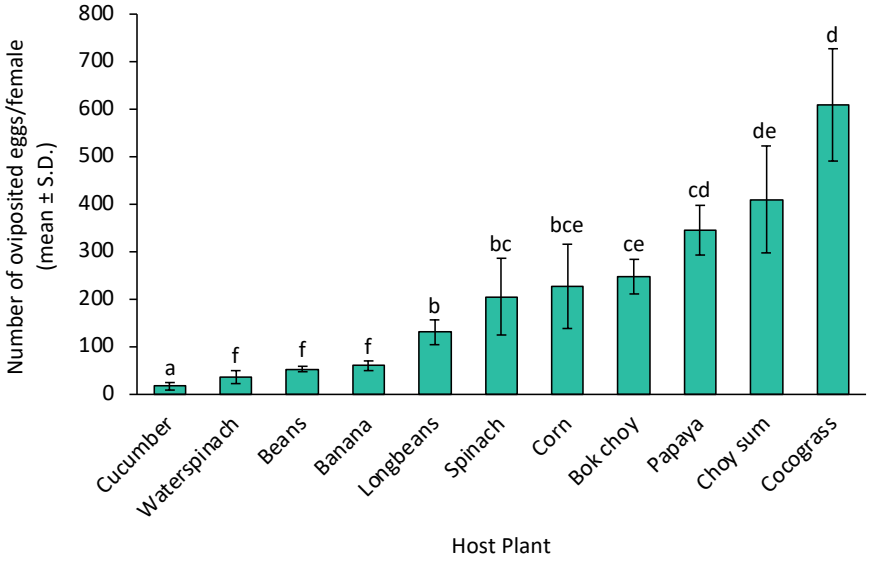

Figure 3. Fecundity of adult female *Spodoptera frugiperda* feed on various host plant species. SD, standard deviation. Means with different letter are significantly different by Tukey HSD Test (α = 0.05).

levels of attack [9, 31, 32]. Hill [33] mentioned that any pest has the potential to become a major pest, and every plant from a different region has its own unique traits. Many species that cause significant damage to one crop may only have minor effects on other crops or even the same crop in a different region of the world. Numerous studies have shown that the host plant species had a substantial impact on the life histories of insects. For example [20, 24]. More information is required to understand the survival, life cycle, and fecundity of *S. frugiperda* on different host plants. Do alternate host plants have the capacity to fully support their development? We hypothesized that some host plants of *S. frugiperda* only serve as a shelter, and some can be alternate hosts for *S. frugiperda*. Different host plants will generate different survival rates, life cycles, and fecundity of an insect. Chen et al. [20] stated that different types of diet could affect the number of larval instars passed through by *S. frugiperda*. A short life cycle and a high survival rate of insects will result in a fast growth rate for an insect population. The shorter the insect life cycle, especially the larval phase, the better the nutritional quality of the food. This quality largely determines the initial phase from larvae to adults. Thus, what the larvae eat at the beginning of their growth will greatly impact the fecundity of the female [34, 35, 36]. Therefore, we study the survival, development time, and fecundity of *S. frugiperda* using 14 potential host plants species.

The host plants had a substantial impact on *S. frugiperda*'s survival rate, development time, and fecundity. Although most of the plants examined in this study were found to be among the 353 species of host plants for *S. frugiperda*, only 11 out of the 14 plants evaluated in this study were able to support the development of *S. frugiperda* completely from egg to adult. *Spodptera frugiperda* was able to survive better when the larvae fed on corn as its host. However, several studies reported the lower survival rate of *S. frugiperda* fed on corn than those reported in this study [35, 36, 37, 38]. Possible causes of this result include plant parts used, varieties, and environmental conditions such as topography, temperature, and humidity [35, 39]. The larvae fed on papaya showed the same survival ability. However, the leaves and seeds of papaya are reported to be effective insecticides for fall armyworms [40, 41, 42]. Besides, fall armyworms fed on papaya could produce higher fecundity than those fed on corn. Other investigations have found variations in *S. frugiperda* survival rates in related plants. Contrary to what Wijerathna et al. [43] reported, *S. frugiperda* fed on

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beans had a greater survival rate. To the contrary, *S. frugiperda* larvae that fed on beans developed more slowly than those that fed on other plants.

Figure 4. Heat map representation of possible attack rate of *Spodoptera frugiperda* when the host plant intercropped each other.

The development time of *S. frugiperda* fed on corn and spinach were comparable in this study. In contrast, Maruthadurai & Ramesh [2] reported that the development time of *S. frugiperda* fed on spinach was longer than those fed on corn. But according to the findings of our study, *S. frugiperda* fed on corn had a higher fecundity than *S. frugiperda* fed on spinach. When fed on water spinach instead of corn, *S. frugiperda* developed more slowly and had a lower fecundity. In the meantime, Putra & Martina [19] noted that *S. frugiperda*'s fecundity was significantly higher when fed on water spinach compared to when fed on corn.

Another brassicae members such as broccoli, cabbage, and cauliflower might be regarded as the least suitable hosts for *S. frugiperda* because these plants couldn't fully support *S. frugiperda*'s development. The life cycle of *S. frugiperda* fed on broccoli, cabbage and cauliflower stopped when the larvae at the 4th and 5th instar. Thus, no *S. frugiperda* became adults in those treatments. This result is different from the results reported by Wang et al. [44], reporting that *S. frugiperda* could survive when reared with Chinese cabbage [*Brassica pekinensis* (Lour.) Rupr. var. Qinza 2] even with a very low survival rate. Wijerathna [43] reported that *S. frugiperda* could survive when reared with cabbage, even with low adult fecundity, which contrasts with those reared with bok choy (*Brassica rapa* subsp. *chinensis*) and choy sum (*Brassica rapa* subsp. *chinensis* var. *parachinensis*). Despite their same genus

(*Brassica*), bok choy and choy sum resulted in a higher survival rate of *S. frugiperda* compared to those three plants. In addition, *S. frugiperda* also had a faster development time and more fecundity when fed on bok choy and choy sum compared to corn as its main host. In addition, Putra & Khotimah [45] noted that the life cycle of *S. frugiperda* was accelerated and its fecundity increased when fed on bok choy, even in circumstances when corn was available as its primary host.

Except for coco grass, almost all the host plants investigated in this study have commercial value. Unexpectedly, *S. frugiperda* fed on coco grass had a survival rate that was nearly equal to that of *S. frugiperda* fed on corn, papaya, water spinach, banana, and spinach. In addition, *S. frugiperda* larvae fed on coco grass had the highest fecundity compared to other host plants. Apart from this weed, other weeds, such as napier and natal grass, have also been reported to support the development of *S. frugiperda* in Taiwan [20]. Weeds are competitors for cultivated plants. However, the fact that *S. frugiperda* can survive on some weeds creates a problematic situation. The presence of weeds can be a competitor for cultivated plants because apart from affecting soil and plant nutrition [46], research results show that the presence of weeds (coco grass) can also potentially increase *S. frugiperda* attacks. However, weeds can be used as alternate hosts by using them as trap or hedge plant. Our results implies that these plants can be used in determining control strategies such as inter-cropping or push-full systems. There are other factors to be assessed, considering that the simultaneous planting of these plants is possible to increase the attack rate of *S. frugiperda*. For example, when the main host is not available or when the growing season changes, *S. frugiperda* can switch back to its main host [39]. In addition, the polyphagous nature of *S. frugiperda* can support transfers between one host plant to another [11]. For example, *S. frugiperda* infestation on cotton in Brazil, where cover crops such as millet may act as an agent that exacerbates the attack rate in the following growing season [47]. Another alternative control method is by regulating the planting time. Regulation of planting time is needed to break the life cycle of *S. frugiperda* in the field.

5. Conclusions

In conclusion, the best host plant for *S. frugiperda* is corn in Indonesia. The ability of *S. frugiperda* to survive on papaya, water spinach, banana, spinach, cucumber, and coco grass indicates that these plants potentially become alternate hosts for *S. frugiperda*. Long beans, bok choy, choy sum, and beans can be categorized as a shelter for *S. frugiperda*. Meanwhile, cabbage, broccoli and cauliflower are the least suitable hosts for *S. frugiperda*. The findings of this investigation support's research [35], according to the findings that despite being regarded as a polyphagous insect, *S. frugiperda* is closely connected with corn and has a lower potential as a feeder of the other host plants. As a result, in the absence of its favored hosts, *S. frugiperda* can potentially harm other host plants and adapt them during the invasion process.

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